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Die präglaziale und interglaziale Umwelt der lnsel Banks: Pollen- und Makrofossilien von der Steilüste von Duck Hawk und anderen verwandten Standorten

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Résumé de l'article

Les falaises Duck Hawk, près de Sachs Harbour, présentent des sédiments dont l'âge varie du Tertiaire jusqu'au Quaternaire supérieur. Le pollen et les macrorestes de végétaux et d'animaux fossiles, prélevés dans divers sédiments non glaciaires dans les falaises Duck Hawk et d'autres sites associés dans les îles de Banks et Victoria, enregistrent des variations climatiques et biotiques au cours de cette période. Au moment de la mise en place des dépôts miocènes-pliocènes de la Formation de Beaufort, une forêt conifériennne, composée de plusieurs espèces de conifères et de divers feuillus, existait au sud de l'île de Banks. Un membre supérieur de la Formation de Beaufort est caractérisé par une forêt conifériennne appauvrie bien que plusieurs plantes, maintenant disparues de l'ensemble des T.N.-O., ont été identifées. La Formation de Worth Point, datant de la fin du Tertiaire et du Quaternaire inférieur, a été mise en place lorsqu'une toundra forestière, dominée par le mélèze, caractérisait l'île de Banks méridionale. Le mélèze croissait peut-être dans l'île lors de l'interglaciaire subséquent de Morgan Bluffs (>730 ka BP), mais les autres indicateurs permettent de croire que la faune et la flore étaient caractéristiques de celle du bas Arctique. Des conditions semblables ont existé lors de l'interglaciaire de Cape Collinson (= Sangamon), bien qu'à ce moment les conifères avaient définitivement disparu de l'île.

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PREGLACIAL AND INTERGLACIAL ENVIRONMENTS OF BANKS ISLAND: POLLEN AND MACROFOSSILS FROM DUCK HAWK BLUFFS AND RELATED SITES*

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ABSTRACT Sediments ranging in age from Tertiary to Late Quaternary are exposed at Duck Hawk Bluffs near Sachs Harbour on Banks Island (NWT). Fossil pollen and macrofossils of plants and arthropods from various nonglacial sediments at Duck Hawk Bluffs and related sites on Banks and Victoria islands make it possible to infer some of the climatic/biotic changes during that time span. At the time of deposition of the Miocene-Pliocene Beaufort Formation, southern Banks Island supported a rich coniferous forest, containing several species of conifers and various hardwoods. An upper member of the Beaufort Fm. is characterized by a more depauperate coniferous forest assemblage, yet still contains plants now foreign to the entire NWT. The late Tertiary/early Quaternary Worth Point Formation was deposited when larch-dominated forest-tundra characterized southern Banks Island. Larch may have grown on the island during the following Morgan Bluffs Interglaciation (>730 ka), but in other respects the flora and fauna of that time seem to have been low Arctic in character. Similar conditions existed during the Cape Collinson Interglaciation (= Sangamon), though by that time, coniferous trees had definitely disappeared from the island.

RÉSUMÉ *Les environnements préglaciaires et interglaciaires de l'île de Banks: pollen et macrofossiles des falaises Duck Hawk et d'autres sites associés.* Les falaises Duck Hawk, près de Sachs Harbour, présentent des sédiments dont l'âge varie du Tertiaire jusqu'au Quaternaire supérieur. Le pollen et les macrorestes de végétaux et d'animaux fossiles, prélevés dans divers sédiments non glaciaires dans les falaises Duck Hawk et d'autres sites associés dans les îles de Banks et Victoria, enregistrent des variations climatiques et biotiques au cours de cette période. Au moment de la mise en place des dépôts miocènes-pliocènes de la Formation de Beaufort, une forêt coniférienne, composée de plusieurs espèces de conifères et de divers feuillus, existait au sud de l'île de Banks. Un membre supérieur de la Formation de Beaufort est caractérisé par une forêt coniférienne appauvrie bien que plusieurs plantes, maintenant disparues de l'ensemble des T.N.-O., ont été identifées. La Formation de Worth Point, datant de la fin du Tertiaire et du Quaternaire inférieur, a été mise en place lorsqu'une toundra forestière, dominée par le mélèze, caractérisait l'île de Banks méridionale. Le mélèze croissait peut-être dans l'île lors de l'interglaciaire subséquent de Morgan Bluffs (> 730 ka BP), mais les autres indicateurs permettent de croire que la faune et la flore étaient caractéristiques de celle du bas Arctique. Des conditions semblables ont existé lors de l'interglaciaire de Cape Collinson (= Sangamon), bien qu'à ce moment les conifères avaient définitivement disparu de l'île.

ZUSAMMENFASSUNG *Die präglaziale und interglaziale Umwelt der Insel Banks: Pollen- und Makrofossilien von der Steilküste von Duck Hawk und anderen verwandten Standorten.* An den Steilküsten von Duck Hawk in der Nähe von Sachs Harbour auf der Insel Banks (Nord-West-Territorien) befinden sich Sedimente, deren Datierung vom Tertiär bis zum späten Quaternär reicht. Fossiler Pollen und Makrofossile von Pflanzen und Gliederfüßern von verschiedenen nichtglazialen Sedimenten der Steilküsten von Duck Hawk und verwandten Standorten auf den Inseln Banks und Victoria erlauben, auf einige klimatische/biotische Veränderungen während dieser Zeitspanne zu schlißen. Während der Ablagerung der Miozän- Pliozän-Formation von Beaufort bedeckte ein reicher Nadelwald die südliche Insel Banks, bestehend aus verschiedenen Arten von Nadelbäumen und verschiedenen Laubbäumen. Ein höherer Teil der Beaufort-Formation ist durch eine ärmere Nadelbaumbewaldung gekennzeichnet, enthält jedoch immer noch Pflanzen, die heute in den gesamten Nord-West-Gebieten unbekannt sind. Als im späten Tertiär und frühen Quaternär die Worth Point-Formation abgelagert wurde, war der südliche Teil der Insel Banks durch eine von Lärchen beherrschte Baum-Tundra gekennzeichnet. Lärchen wuchsen wohl auf der Insel während der folgenden Interglazialzeit von Morgan Bluffs (>730 ka), jedoch weisen andere Indizien darauf hin, daß die Flora und Fauna dieser Zeit in ihrem Charakter derniedrigen Arktis entsprach. Ähnliche Bedingungen bestanden während der Interglazialzeit von Cape Collinson (= Sangamon), obwohl zu diesem Zeitpunkt Nadelbäume endgültig von der Insel verschwunden waren.

* Geological Survey of Canada Contribution 14886

INTRODUCTION

Banks Island is situated in an area where Laurentide ice, spreading from dispersal centres on the mainland to the southeast, reached its limit on at least three occasions. Detailed mapping and stratigraphic investigations (VINCENT, 1982, 1983, 1984; VINCENT *et al.*, 1983) have revealed fossil-bearing terrestrial sediments of presumed preglacial, interglacial, and possibly interstadial ages. The best studied and most varied sequence occurs at Duck Hawk Bluffs (= DHB) near the community of Sachs Harbour on the southwestern part of the Island (Fig. 1).

This paper deals with study of pollen, plant macrofossils and insects from preglacial, interglacial, interstadial and postglacial sediments exposed chiefly at the DHB exposure. But fossils from other related sites on Banks and Victoria Island are also discussed (Fig. 1). The paper is actually a reconnaissance effort, intended primarily as a beginning in the process of characterizing different North American Arctic interglaciations in terms of their flora and fauna as has been done in Europe (VAN DER HAMMEN *et al.*, 1971). Sites such as DHB offer unique opportunities for accomplishing this objective because they contain organic sediments representing much of the late Cenozoic. But the length of this record at DHB also poses some problems, chief of which is the potential for rebedding of fossils, particularly of pollen.

Most samples analyzed for this paper were collected by J.-S. Vincent and S. Occhietti in 1981, as part of a detailed study of the stratigraphy of the DHB exposure. In 1985 additional samples were collected by Matthews during a joint Canadian-American excursion to the Beaufort Sea coast.

QUATERNARY STRATIGRAPHIC FRAMEWORK FOR BANKS ISLAND

The complex Quaternary framework of Banks Island is discussed by VINCENT (1982, 1983 and 1984) and VINCENT *et al.* (1983). It is summarized in Figures 1, 2, 3 and 4.

PREGLACIAL EVENTS

Miocene (?) sands and gravels of the Beaufort Fm. underlie the Quaternary sediments at most of the DHB exposures. Like Beaufort Fm. exposures on northern Banks Island and on some of the Queen Elizabeth Islands (HILLS, 1969), two Beaufort Fm. members appear to be represented at DHB (see below). To the east towards Sachs Harbour from Sections I and I' (Fig. 2a) beds of the Upper Cretaceous Kanguk Fm. occur beneath the Beaufort Fm. The Kanguk Fm. consists of friable siltstone containing several prominent tephra horizons.

Terrestrial non-glacial deposits overlying Beaufort Fm. sediments and underlying deposits of the Banks Glaciation (Duck Hawk Bluffs Fm.) are assigned to the Worth Point Fm.

FIGURE 1. Location map (modified from VINCENT, 1983) showing extent of glaciation on Banks Island and sites mentioned in text. Shown are ice limits for each of the three recognized glaciations of Banks Island: the Banks Glaciation (oldest), Thomsen Glaciation and Amundsen Glaciation (youngest). Note the abbreviations for sites as used in the text and for headings in Tables I, II and III.

Carte de localisation (d'après VINCENT, 1983) montrant les limites glaciaires dans l'île de Banks et aux sites mentionnés dans le texte. Les limites glaciaires des trois glaciations reconnues dans l'île de Banks sont indiquées sur la carte: la Glaciation de Banks (la plus vieille), la Glaciation de Thomsen et la Glaciation d'Amundsen (la plus jeune). Les abréviations des sites sont utilisées dans le texte et dans le titre des tableaux I, II et III.

(VINCENT *et al.*, 1983). The type section is at Worth Point (Fig. 1) where several organic layers are exposed in the sediment fill of a small valley incised into Cretaceous (Kanguk Fm.) and Tertiary (Beaufort Fm.) deposits (VINCENT, 1983). The section was best exposed when it was studied by M. Kuc in 1969. Since then the exposure has degraded to the extent that it has not been possible to replicate Kuc's original sample series. Nevertheless, the organic sediments which he described and illustrated unquestionably belong to the Worth Point Fm. because they rest on Beaufort Fm. and underlie Bernard Till of the Duck Hawk Bluffs Fm.

The Worth Point Fm. at DHB was considered by VINCENT *et al.* (1983) to consist of two units; an upper eolian member, exposed at most localities and containing thick peats and ice-wedge pseudomorphs, and a lower fluvial member seen only at section G. Evidence presented here shows that the lower member is best considered an upper member of the Beaufort Fm. (Fig. 2b).

Worth Point Fm. sediments at DHB are apparently older than 730 ka (the Brunhes/Matuyama boundary) because the eolian member, as well as the overlying sediments within the Duck Hawk Bluffs Fm. and Morgan Bluffs Fm. are magnetically reversed (VINCENT *et al.*, 1984; Fig. 3). No glaciogenic sediments are found in or below the Worth Point Fm.; hence it is probably preglacial in age.

BANKS GLACIATION

The earliest recognized Laurentide glaciation to have reached Banks Island is the Banks Glaciation (VINCENT, 1982 and 1983). It covered most of the Island, except for the

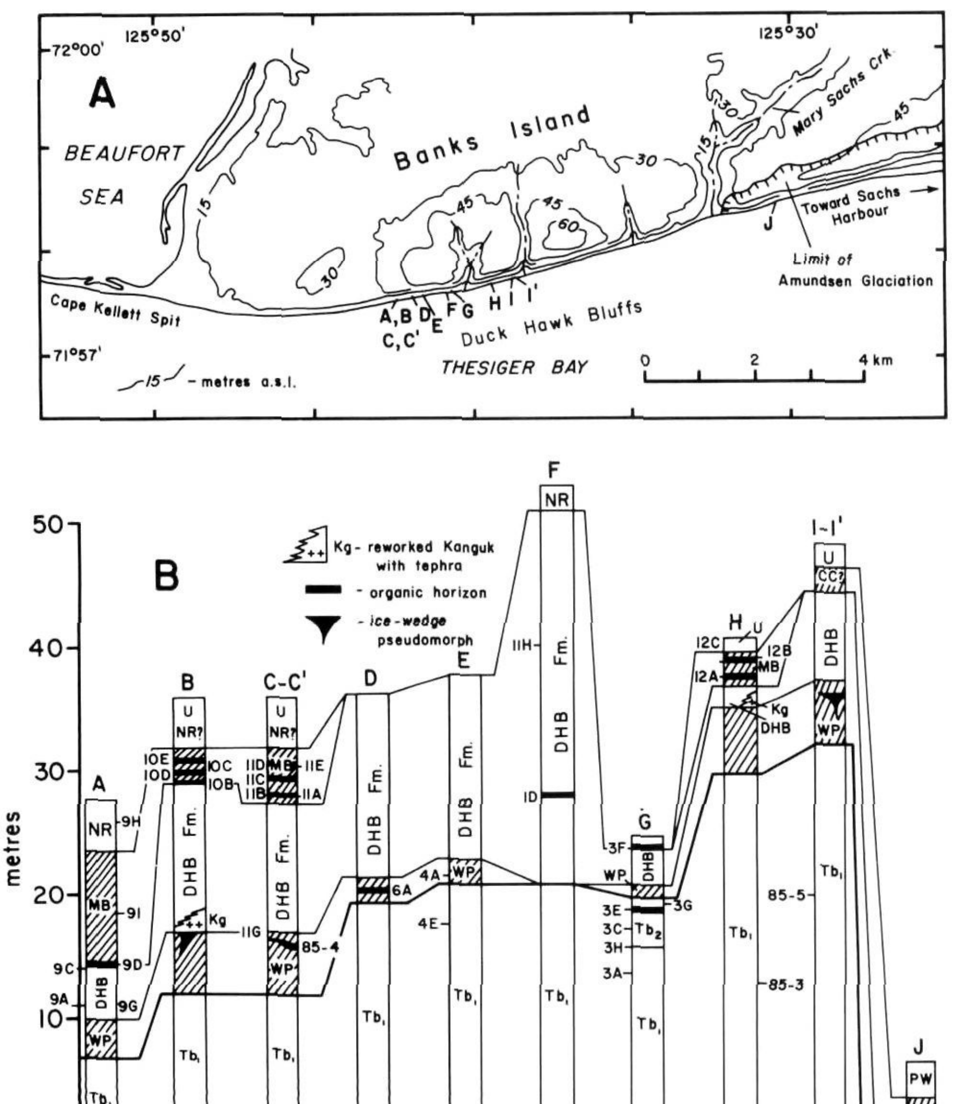


FIGURE 2. A. Map showing location of studied exposures at Duck Hawk Bluffs. B. Sections at Duck Bluffs, based on Figure 3 of VINCENT *et al.* (1983). Cross-hatching marks the Worth Point, Morgan Bluffs and Cape Collinson beds. Numbers next to the columns refer to samples from which pollen and/or macrofossils (including wood) have been obtained by Vincent and Occhietti (VH-81-9c, etc) or Matthews (MRA 7-24-85-3, etc.) or samples which were studied for their paleomagnetism.

A. Carte de la localisation des coupes étudiées dans les falaises Duck Hawk. B. Les coupes dans les falaises Duck Hawk, d'après la figure 3 de VINCENT et al. *(1983). Les hachures indiquent la position des lits des formations de Worth Point, de Morgan Bluffs et de Cape Collinson. Les numéros près des colonnes identifient les échantillons, prélevés par Vincent et Occhietti (VH-81-9C, etc.) ou de Matthews (MRA 7-24-85-3, etc.), qui ont livré du pollen ou des macrofossiles ou qui ont été utilisés pour les études sur le paléomagnétisme.*

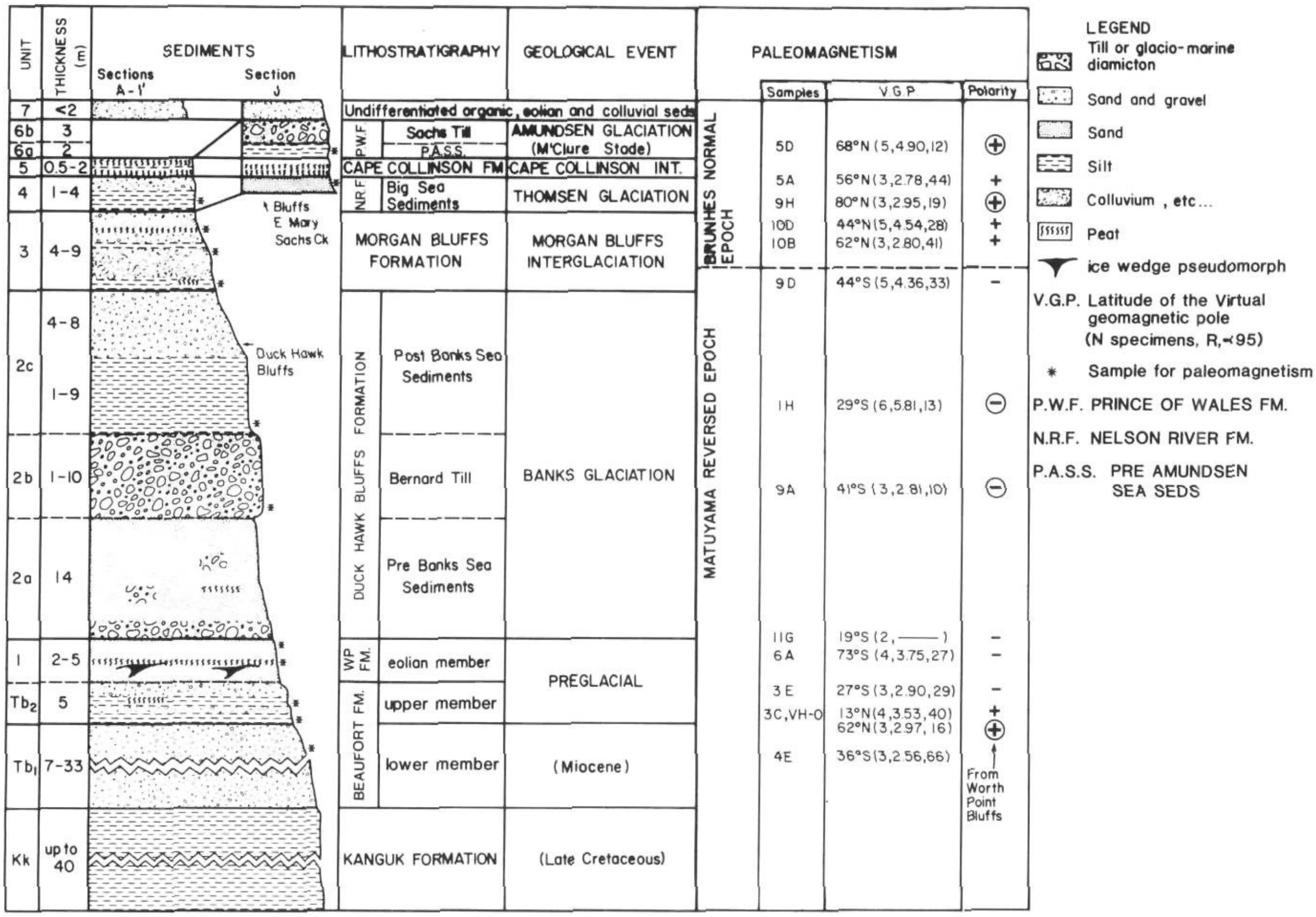


FIGURE 3. Composite stratigraphic section of Duck Hawk Bluffs (after VINCENT *et al.*, 1984). Sample numbers refer to samples collected by Vincent and Occhietti and are abbreviated forms of VH-81-5D, VH-81-9D, etc. For location of samples at various sections see Fig. 2b.

Coupe stratigraphique composite des falaises Duck Hawk (d'après VINCENT et al., *1984). Les numéros identifient les échantillons prélevés par Vincent et Occhietti; ils sont une forme abrégée de VH-81-5D, VH-81-9D, etc. La localisation des échantillons est indiquée à la figure 2b.*

unglaciated northwest sector, and is probably the only Laurentide glaciation extensive enough to have covered large areas of the Western Queen Elizabeth Islands. Magnetically reversed glaciogenic (Bernard Till) and marine deposits representing the Banks Glaciation are assigned to the Duck Hawk Bluffs Fm. They are the surface materials over large areas of Banks Island (Fig. 1) and are found in all the Quaternary sections at DHB (Fig. 2B). In sections B and H at DHB (Fig. 2b) thin tephra-bearing Kanguk Fm. sediments are found immediately under Bernard Till and above Beaufort Fm. gravels and Worth Point Fm. eolian sands. These "pockets" of the Kanguk Fm. are thought to have been carried at the sole of the Banks glacier and thrust to their present position.

MORGAN BLUFFS INTERGLACIATION

Organic bearing non-glacial deposits overlie marine and glacial sediments associated with the Banks Glaciation and underlie marine and glacial sediments associated with the Thomsen Glaciation (Fig. 1 and 2b; VINCENT, 1983 and 1984) at five locations on Banks Island. These organic sediments are assigned to the Morgan Bluffs Fm. and were deposited during the Morgan Bluffs Interglaciation (Fig. 3). Paleomagnetic studies at DHB show that the Morgan Bluffs Fm. probably includes the Brunhes-Matuyama boundary (Fig. 3) (VINCENT, *et al.*, 1984). If so, the Morgan Bluffs Interglaciation is approximately 730 ka old.

Correlation of the various beds assigned to the Morgan Bluffs Interglaciation is based mainly on their stratigraphic position. Organics exposed along the Thomsen River (= TR, Fig. 1) and in the "Ivitaruk" River bluffs (= IR, Fig. 1) are correlated with the Morgan Bluffs Fm. because they occur in fluvial sediments that lie between Bernard Till (Duck Hawk Bluffs Fm.) of the Banks Glaciation and Baker Till (Nelson River Fm.) of the younger Thomsen Glaciation (VINCENT, 1983).

In some cases the process of correlating presumed Morgan Bluffs deposits has been augmented by Uranium series dates and amino acid analyses. For example, amino acid ratios on fossil wood from interstratified perimarine deposits in the bluffs east of Nelson River (= ENR, Fig. 1) suggest correlation with a similar suite of sediments at the Morgan Bluffs type locality east of Jesse Bay (= EJB, Fig. 1) (VINCENT, 1983). And a recently obtained Uranium-Thorium date (>200 ka BP; UQT-239) suggests that the uppermost organics at Section H are of Morgan Bluffs Interglaciation age rather than of Cape Col-

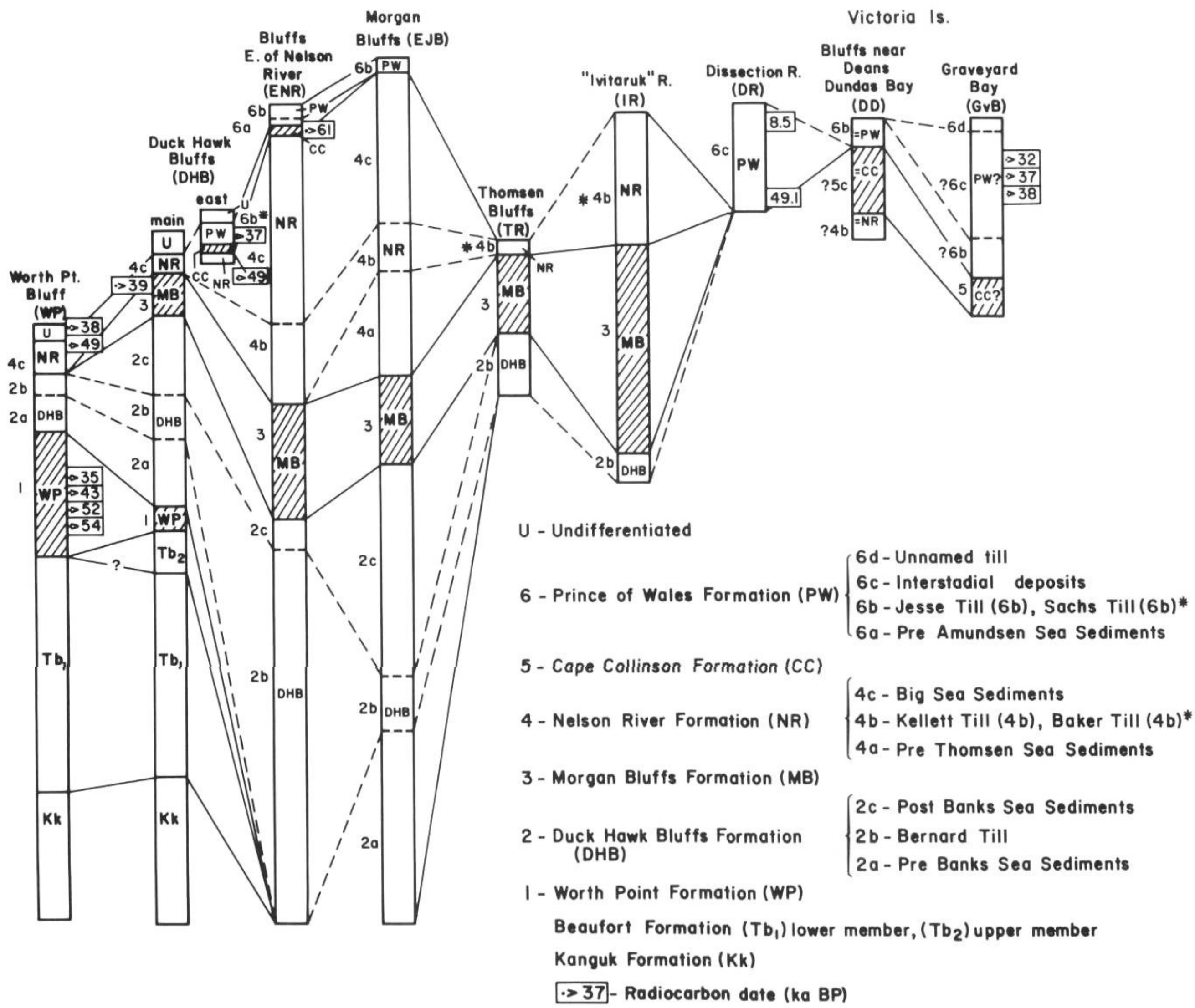


FIGURE 4. Composite sections and probable correlation of the various exposures on Banks Island and Victoria Island as discussed in the text. See Fig. 1 for location of sections.

Coupe composite et corrélation probable entre les diverses séquences stratigraphiques des îles de Banks et Victoria. Voir la figure 1 pour la localisation des coupes.

linson Interglaciation age as tentatively suggested by VINCENT *et al.* (1983, p. 1708). Thus beds in which samples VH-81-12A, B and C (Fig. 2b) were collected are now included within the Morgan Bluffs Fm.

Generally, however, chronologic control is inadequate and this means there is a possibility that some of the deposits referred to the Morgan Bluffs Interglaciation actually represent other warm intervals (see below.) This is particularly true at the Morgan Bluffs Fm. type locality (EJB).

THOMSEN GLACIATION

During the Thomsen Glaciation northwestward-flowing Laurentide ice overrode large areas of southern and eastern Banks Island and the Thomsen River basin (Fig. 1). The Thomsen Glacier did not reach DHB; and consequently, is represented there only by marine sediments (the Big Sea) within the Nelson River Fm. The absolute age of the Thomsen Glaciation is not definitely known. But it does predate the last interglacial because its deposits underlie sediments of the Cape Collinson Interglaciation, and it is probably no older than the start of the Brunhes Epoch.

CAPE COLLINSON INTERGLACIATION

At two locations on Banks Island, organic-bearing, non-glacial deposits assigned to the Cape Collinson Fm. overlie marine and glacial sediments associated with the Thomsen Glaciation (Nelson River Fm.) and underlie marine and glacial sediments associated with the Amundsen Glaciation (Prince of Wales Fm.; Fig. 3; VINCENT, 1983). At the ENR type section, Cape Collinson sediments consisting of pond deposits radiocarbon-dated at > 61 ka (QL-1230) overlie marine (Big Sea) sediments associated with the Thomsen Glaciation and underlie Pre-Amundsen Sea Sediments and Jesse Till, both of which are associated with the presumed Early Wisconsinan

M'Clure Stade of the Amundsen Glaciation. In the bluffs east of Mary Sachs Creek near DHB (section J, Figs. 2a and 2b) peat beds within the Cape Collinson Fm., dated at > 49 ka (GSC-3560-2), overlie Big Sea Sediments and underlie Pre-Amundsen Sea glaciomarine sediments and Sachs Till.

On Victoria Island two sites, a coastal bluff along Deans Dundas Bay and a river bluff close by (DD; Fig. 1) are directly across Prince of Wales Strait from the EJB locality. Sub-till alluvium from these contains organic lenses that are thought to predate the M'Clure Stade and are tentatively assigned to the Cape Collinson Interglaciation (VINCENT and HODGSON, in prep.).

AMUNDSEN GLACIATION

Laurentide ice of the Wisconsinan Amundsen Glaciation impinged on the coastal areas of Banks Island on two distinct occasions: the earlier M'Clure Stade and the following Russell Stade. Glacial and marine sediments associated with the M'Clure Stade overlie Cape Collinson Interglacial sediments in the bluffs east of Mary Sachs Creek (Fig. 2b) and ENR (VINCENT, 1983; VINCENT *et al.*, 1983). Radiometric data and the general paleogeographical framework of the western Arctic Archipelago indicate that M'Clure Stade may pre-date the Late Wisconsinan (VINCENT, 1982, 1983 and 1984). Based on radiocarbon dates obtained on shells collected in marine sediments underlying and overlying till left by the Viscount Melville Sound Ice Shelf, it is estimated that continental ice of the Russell Stade last impinged on the northeastern tip of Banks Island at 10 ka (HODGSON and VINCENT, 1984). If the Early and Late Wisconsinan ages respectively assigned to the M'Clure and Russell stades are correct, a record of the long interstadial period which existed between the two stades should be found on Banks Island. Among the various deposits believed to date from this interval are the fluvial sands and gravels with organics in bluffs on Dissection River (DR, Fig. 1) on Banks Island and the Graveyard Bay site (hereafter referred to as the GvB site, Fig. 1) on Victoria Island.

FLORA AND FAUNA OF BANKS ISLAND

Banks Island currently possesses a cold Arctic climate, with a mean annual daily temperature at Sachs Harbour of −14.1°C (ATMOSPHERIC ENVIRONMENT SERVICE, 1982). All of the island is within the zone of continuous permafrost, and ground ice structures such as ice wedges are actively forming.

FLORISTICS

The flora of Banks Island contains 186 vascular species; that of Victoria Island 207 species (DANKS, 1981). Both islands are beyond the northern range of conifers and alders. Banks Island also lacks some of the ericaceous genera (*e.g., Ledum, Empetrum, Vaccinium*) that are so common in the tundra further south. Shrub birch (*Betula glandulosa*), which is also a prominent component of the flora on the northern mainland, has only been found at one locality — a warm, south-facing slope in the well protected Masik River Valley (KUC, 1970) on southern Banks Island (Fig. 5). Also apparently missing from the Banks Island flora are *Menyanthes, Sparganium* and *Potamogeton*. The mainland distribution of some of these species and others represented by fossils from DHB is shown in Figure 5.

Figure 5 also includes a map showing floral zones on the island. It shows both DHB and ENR in the Low Arctic zone. Thomsen River and the IR site occur near YOUNG's (1971) zone 3/2 boundary and thus exist in an area with a much different flora from that of southern Banks Island. However there is no general agreement on the location of zonal boundaries or even of the number of zones. YOUNG (1971) divides tundra into four floristic zones, with the line between his Zone 3 and Zone 2 corresponding approximately with the Mid Arctic/High Arctic division of EDLUND (1983). ALEKSANDROVA (1980) divides the Arctic into three vegetation zones, and her boundary between Low Arctic and Arctic Tundra nearly coincides with the Low Arctic/Mid Arctic boundary shown in Figure 5. BLISS (1977, Fig. 2), on the other hand, places the whole of the Arctic Archipelago within the Arctic Tundra and Polar Desert zones, an assignment disputed by EDLUND (1983) who argues that southern parts of Banks Island and Victoria Island are Low Arctic (Fig. 5 and ENERGY MINES and RESOURCES, 1973) because they have July temperatures in the 5.9-7.9°C range and in places (*e.g.*, on Victoria Island) support tree-size willow. As shown in Figure 5 the 5°C mean July isotherm currently isolates the southern and northern coast of the Island from the slightly milder interior.

ARTHROPOD FAUNA

The arthropod fauna of Banks Island is not as well documented as the flora. DANKS (1981), the only comprehensive summary available for Arctic insects, discusses some of the special problems that make aquisition of knowledge on arthropod ranges more difficult than for plants. Even so, it is obvious that several parallels exist between the distribution of vascular plants and Coleoptera. One of them is an apparent impoverishment of the fauna of the northern part of the island compared to that of the DHB area. *Amara alpina* is probably the only carabid beetle (family Carabidae) that lives on the northern part of the island. The faunas at the TR site, Dissection Creek (hereafter, DR) and the IR site undoubtedly also include a few staphylinids and one or two weevils, but they are probably less diverse than the fauna at DHB.

The beetle fauna of the DHB region includes several species of carabids, among them *Amara alpina*, *Bembidion umiatense*, at least two species of the subgenus *Cryobius* (genus *Pterostichus*), several staphylinids (possibly including *Micralymma brevilinque*) and the weevils *Rhynchaenus arctica* and *Lepyrus*. Although it is one of the most common beetles of dry sites on the Mainland, the weevil *Lepidophorus lineaticollis* has not been recorded from Banks Island. Likewise it is also doubtful that some of the carabid beetles represented by fossils (*Carabus truncaticollis, Diacheila polita, Dyschirius, Notiophilus*) or the weevils *Notaris* and *Vitavitus thulius* occur today on Banks Island.

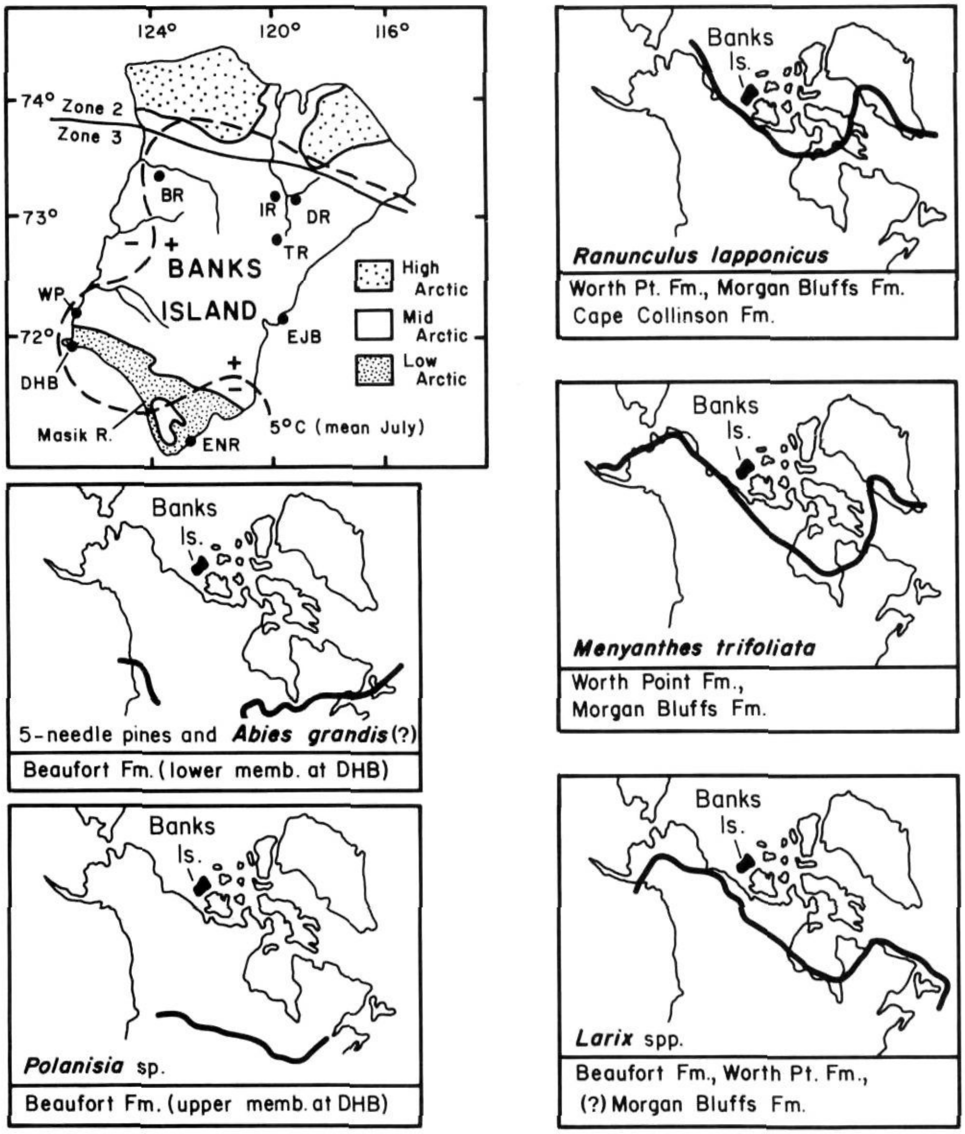


FIGURE 5. Vegetation zones and 5°C mean July isotherm on Banks Island (after VINCENT and EDLUND, 1978; EDLUND, 1986; and YOUNG, 1971) and current northern limit for some of the plant taxa found as fossils (after PORSILD and CODY, 1975 and ILTIS, 1957). Note the differences in the present northern limit of plants from the various formations.

Les zones de végétation et isotherme moyen de 5°C en juillet à l'île de Banks (d'après VINCENT et EDLUND, 1978; EDLUND, 1986; YOUNG, 1971). La limite septentrionale actuelle de diverses plantes (d'après PORSILD et CODY, 1975; ILTIS, 1957) trouvées sous forme de fossiles, est indiquée. À noter les différences entre la localisation de la limite actuelle des plantes et les endroits où elles ont été trouvées fossilisées dans les dépôts plus anciens.

PALYNOLOGY

BEAUFORT FORMATION

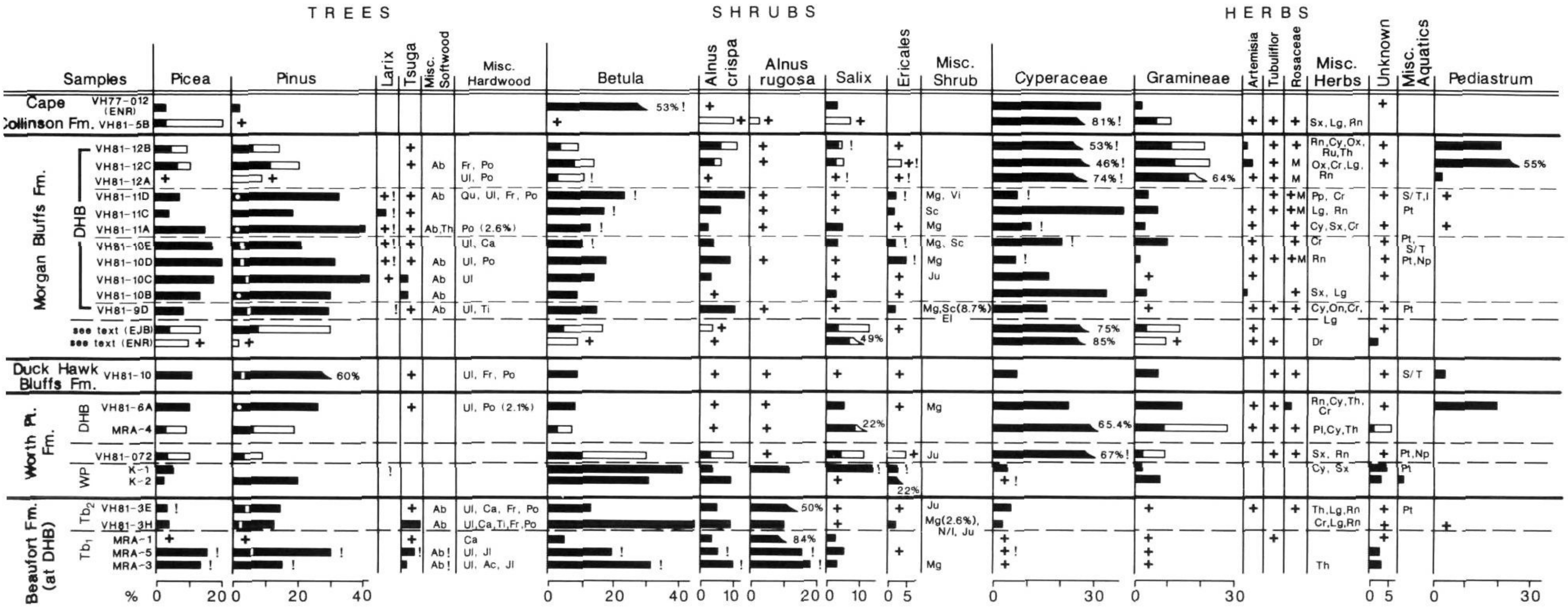
Pollen spectra of three samples from the lower member of the Beaufort Formation are shown in Figure 6. One of the samples is dominated by *Alnus rugosa* type pollen (84%) and thus has limited significance. The other two show more than 10% *Picea* pollen, 15-30% *Pinus* pollen (some of which is of the white pine or Haploxylon type), more than 20% *Betula*, significant amounts of both the *Alnus crispa* and *Alnus rugosa* types and only trace amounts of sedge and grass. They also contain traces of *Abies* pollen, above background quantities of *Tsuga* and traces of hardwoods such as *Juglans* and *Ulmus*. The diagram also shows that the major pollen types, including *Abies*, are also represented by macrofossils. Most of the birch pollen from samples MRA 7-24-85-3 and MRA 7-24-85-5 are greater than 20 microns in diameter, placing them in the tree-birch size range.

Two samples (VH-81-3H and 3E) from the upper member of the Beaufort Fm. display moderate values for *Picea*, more than 10% pine and moderate to high values for *Betula*, some of which must represent one or more arboreal species. Sample VH-81-3E contains nearly 50% *Alnus rugosa* type pollen. The two also contain one or more types of hardwood pollen such as *Ulmus, Tilia, Carya, Fraxinus*, and 3H has more than 5% *Tsuga* pollen.

WORTH POINT FORMATION

Three of the spectra in Figure 6 are from the Worth Point area, two (K-1, K-2) from the Worth Point type section and one, VH-81-072, which is only tentatively referred to the Worth Point Fm., is from a coastal site 3 km south. The remaining two Worth Point Fm. samples in Figure 6 are from DHB.

There is uncertainty concerning the provenance of the two samples (K-1 and K-2) collected by M.Kuc. K-2 probably



+ = 2% or less; ! signifies associated macrofossils; white bar = % with Cyperaceae extracted; white bar for pine = % of Pinus Haploxylon type: white circle = <2%

Localities: DHB = Duck Hawk Bluff
EJB = East of Jesse Bay
ENR = East of Nelson River
WP = Worth Point
MRA-4 = MRA-7-24-85-4
MRA-1 = MRA-7-24-85-1
MRA-5 = MRA-7-24-85-5
MRA-3 = MRA-7-24-85-3

Abbreviations: Misc. trees – Ab(ies), Th(uja), Fr(axinus), Po(plar), Qu(erqus), Ul(mus), Ca(rya), Ti(lia), Jl=Juglans, Ac(er)
Shrubs – Mg=Myrica, Vi(burnum), Sc=Shepherdia canadensis, Ju(niperus), N/I=Nemopanthum/Ilex, El=Elaeagnus commutata
Herbs – Sx=Saxifragaceae, Lg=Legume, Rn=Ranunculus, Cy=Caryophyllaceae, Pp=Polygonum persicaria, On(agraceae), Dr(yas), Ox(yria digyna), Pl=Polygonaceae, T(halictrum), Ru(biaceae), C(ruciferae)
Aquatics – S/T=Sparganium/Typha, Pt=Potamogeton, Np=Nuphar, I(soetes)

FIGURE 6. Pollen diagram of samples from Duck Hawk Bluffs and associated sites on Banks Island. Percentages are calculated on a pollen sum comprising total pollen (including Cyperaceae) exclusive of the pollen of some aquatic taxa and spores. Miscellaneous hardwoods, shrubs, herbs and aquatics are listed by abbreviations only. The designation "NA" in the column for *Alnus crispa* indicates that the species of *Alnus* was not determined. Spores observed include undetermined trilete and monolete types as well as *Sphagnum, Osmunda* and two species of *Lycopodium*. Samples are grouped by stratigraphic unit. Those from DHB are from different sections (Fig. 2b), and are not plotted in stratigraphic order. The "VH", "MRA" and "K" numbers refer respectively to Vincent's, Matthews' and Kuc's original field numbers. For location of DHB samples see Figure 2.

*Diagramme pollinique des échantillons des falaises Duck Hawk et d'autres sites associés de l'île de Banks. Les pourcentages sont calculés sur une somme pollinique comprenant le total du pollen (y compris les Cypéracées), mais excluant le pollen de certaines plantes aquatiques et les spores. Les divers feuillus, arbustes, herbes et plantes aquatiques sont désignés par des abréviations. La désignation "NA", dans la colonne d'*Alnus *crispa, montre que l'espèce n'a pas été identifiée. Les spores observés comprennent des trilètes et des monolètes non identifiés, ainsi que* Sphaghum, Osmunda *et deux espèces de* Lycopodium*. Les échantillons des falaises Duck Hawk (DHB) proviennent de diverses coupes (Fig. 2b); ils ne sont pas disposés par ordre stratigraphique. Les numéros "VH, "MRA" et "K" se réfèrent aux numéros d'échantillons de Vincent, Matthews et Kuc respectivement. La figure 2 montre la localisation des échantillons DHB.*

comes from "layer 7", a forest bed containing stumps in growth position (KUC, 1974, Fig. 3). The stratigraphic provenance of K-1 is less certain, although it undoubtedly comes from one of the organic zones at the Worth Point type section.

The three samples from the Worth Point area differ substantially; sample K-2 shows nearly 21% pine, K-1 none. Sample VH-81-072 is dominated by sedge pollen (67%), much of it probably of local origin. A recalculation excluding sedge (*Cyperaceae*) yields percentages for *Betula* and *Picea* that are more similar to those in the other WP samples.

Of the two samples from DHB, (VH-81-6A) is from eolian sands, but its content of 20% *Pediastrum* shows that it probably accumulated in a small pond. The presence of > 2 % *Populus* pollen may mean that poplars were growing on the island at the time. The other DHB sample, MRA-7-24-85-4, comes from a peat-filled channel. The spectrum is dominated by sedge pollen, but when this is removed from the count the resulting percentages are similar to those for VH-81-6A.

DUCK HAWK BLUFFS FORMATION

Only a single sample (VH-81-1D in Fig. 6) has been studied from this mainly glacial formation. It is from an organic lens likely transported into sands that are assigned to pre Banks Sea phase (Section F, Fig. 2b). It contains the highest percentage of *Pinus* (60%) of any sample, slightly over 10% spruce, approximately 10% *Betula* and low values for *Alnus* and all herbs.

MORGAN BLUFFS FORMATION

Eleven of the 13 Morgan Bluffs Fm. spectra shown in Figure 6 are from four sections at the DHB exposure (see sample positions in Fig. 2b). One is from the ENR exposure, and the other from the Morgan Bluffs Fm. type locality (EJB).

For DHB samples, values for *Pinus* range from 5-40% with Haploxylon (*Pinus strobus*) type constituting up to 5% in some of them. Of the other major tree/shrub pollen types, *Picea* and *Betula* range between 5-20% and *Alnus* up to 10%. Much of the birch pollen is in the arboreal size-range in spite of the fact that the only birch macrofossils found in some of the samples are of the dwarf shrub type (see below).

Several of the DBH samples contain traces of *Larix* pollen (one > 2%), and most of these also contain *Larix* macrofossils (see below). *Larix* is a notoriously poor pollen producer and often underrepresented in pollen diagrams relative to its importance in a plant community. The DHB spectra also show consistent, but low values for *Tsuga* and *Abies* and most contain traces of pollen of hardwoods such as *Ulmus, Carya, Fraxinus, Tilia*, and *Quercus*. *Populus* occurs in trace amounts in several samples and in sample 11A reaches 2.6%.

The three samples (12A, B, C) from Section H (Fig. 2b) differ from the others at DHB by their much higher percentages of sedge and grass pollen. When sedge is eliminated from the count, percentages of *Picea, Pinus* and *Betula* are similar to the rest of Morgan Bluff Fm. samples at DHB; yet the spectra still stand apart because of their content of significant amounts of *Pediastrum*.

The pollen sample from Morgan Bluffs Fm. sediments at ENR is a combined count of seven samples from different 10-20 cm thick organic lenses in a 9 m thick sequence of perimarine sediments. The spectrum from the type section of the Morgan Bluffs Fm. (EJB) represents the combined count from three samples collected in woody peat layers within a thick perimarine fluvial sequence. These two spectra show lower percentages of *Pinus, Picea* and *Betula* than all of their DHB counterparts except those from section H. (Fig. 2a). One of them is dominated by willow pollen, obscuring its regional implications. There are no data on the size of the birch pollen.

CAPE COLLINSON FORMATION

In Figure 6 the Cape Collinson Fm. is represented by a single sample (VH-81-5B) from east of DHB. It is dominated by sedge pollen. When this is eliminated from the count (under the assumption that all of it is local) *Picea* climbs to > 20%, *Alnus* > 10% and grass > 10%. In contrast with samples from the Morgan Bluffs Fm at DHB, only a trace of *Pinus* is present and the southern hardwood types as well as the conifers *Abies* and *Tsuga* are absent.

The single sample labeled ENR in Figure 6 comes from the Cape Collinson Fm. type section east of Nelson River. Unfortunately its regional significance is largely masked by the probable overrepresentation of locally-derived *Betula* and sedge pollen. Some of the birch pollen is apparently in the dwarf-shrub size range, and even though birch macrofossils from the same sample were too poorly preserved for species determination, most of them are similar in size to the shrub birch type (see below).

FOSSIL WOOD

Fossil wood identifications from a number of levels at DHB and other Banks Island sections are shown in Table I. The table also lists fossil wood from the Beaufort Fm. at Ballast Brook (Fig. 1) (ROY and HILLS, 1972). In keeping with standard paleobotanical practice, ROY and HILLS (1972) assigned a morphogeneric name to each wood taxon from the Ballast Brook exposure; however, they state that most, if not all, of the newly named Beaufort taxa belong to extant tree genera (*e.g., Piceoxylon* = *Picea*).

Only a few fragments of wood from the upper member of the Beaufort Fm. at DHB have been examined. They include *Picea, Abies* and a taxon similar to *Eleagnus*.

All of the wood from the lower member of the Beaufort Fm. at DHB exhibits the scars and rounding that are typical of wood carried by a large, gravel-charged river. Only *Picea* and *Pinus* have been identified to date.

Larix wood is common at Worth Point where KUC (1974) reported stumps of *Larix laricina* up to 26 cm in diameter. They possess extremely narrow growth rings, which probably means that the trees were growing near treeline. The Worth Point Fm. at WP also contains *Picea, Salix* and *Alnus* wood. The latter probably represents *Alnus crispa* since seeds of that species occur in the same deposits. The *Salix* wood listed

TABLE I

Fossils woods from various Banks Island localities[1]

	Beaufort Fm.[2]		Worth Point Fm.		Duckhawk Bluffs Fm.	Morgan Bluff Fm.			Cape Collision Fm.			Prince of Wales Fm.
	Tb_1	Tb_2	WP	DHB		DHB	ENR	EJB	DHB[3]	ENR	DDB	
Picea sp.	3A[4]	3G	+		9G	10D,9C,[4] 9I,11C, 11B?						
Piceoxylon beaufortense	+											
Picea/Larix						11E						
Larix sp.			+		+							
Laricioxylon occidentaloides	+											
Abies sp.		3G			?	10C?						
Abietoxylon koreanoides	+											
Pinus sp.	3A											
Pinoxylon albicauloides	+											
Salix sp.			+	4A	1D	10B,10C, 4A,10E?, 11B,11D, 12A,12C	+	+	5B	+	+	+
Betula sp.										+		
Alnus sp.			+									
Eleagnaceoxylon shepherdiodes	+	3G?										

Notes:
1. Identifications by Mott except for some Beaufort Fm. woods identified and described by ROY and HILLS, 1972.
2. Tb_1 = Beaufort Fm. (lower and Ballast Brook); Tb_2 = Beaufort Fm. (upper); WP = Worth Point; DHB = Duck Hawk Bluffs; ENR = East of Nelson River (type locality of Cape Collinson Fn.); EJB = East of Jesse Bay (type locality for Morgan Bluffs Formation); DDB = Deans Dundas Bay.
3. DHB locality listed for Cape Collision Fm. is actually east of Duck Hawk Bluffs proper (see Fig. 2 section J)
4. Numbers in some columns refer to samples whose location is shown on Fig. 2b.

in the table is likely from one or more of the several species identified on the basis of leaves and twigs by KUC (1974) (see also Table II).

Abundant, well preserved *Larix* wood occurs in Bernard Till at Section A (Duch Hawk Bluffs fm., Fig. 2B). It is quite different from Beaufort Fm. wood and very similar in size and preservation to wood from the Worth Point Fm. at the type locality. Consequently we suspect that it was dredged up from a localized concentration of Worth Point Fm. organics at DHB when the glacier that deposited the Bernard Till moved across the site.

Picea wood and a fragment identified as either *Larix* or *Picea* have been found in the Morgan Bluffs Fm. sediments at DHB. All such coniferous wood comes from the part of the exposure near section A; only willow (*Salix*) is recorded at the eastern end of the exposure (*e.g.*, Section H; Fig. 2b). Willow is also the only wood that has been found in the Morgan Bluffs Fm. at the ENR and EJB exposures (Table I).

The Cape Collinson Fm. beds east of DHB and at the type locality have yielded mainly *Salix* wood. *Betula* wood has been identified at the ENR site (Table I).

PLANT AND ARTHROPOD MACROFOSSILS

BEAUFORT FORMATION

The list of fossils from the Beaufort Fm. (Table II) is a preliminary version of one that is to be published separately (MATTHEWS, in press). Only the assemblage characteristics pertinent to this study are mentioned below.

The > 40 mesh/inch fraction of organic detritus consists mostly of well worn wood fragments, conifer needles and seeds, contrasting markedly to the bryophyte-dominated res-

TABLE II

Plant and arthropod macrofossils from the Beaufort and Worth Point Formations, Banks Island

Taxa	Beaufort lower (Tb_1)[3]	Beaufort upper (Tb_2)	Worth WP[2]	Worth DHB[2]
PLANTS:				
Bryophyta	r[1]		++[4]	++
Equisetaceae				
Equisetum sp.				
Spermatophyta				
Pinaceae				
Abies grandis type	++			
Larix sp.	+			
Larix laricina (DuRoi) K.			+	
Pinus sp. (5-needle type)	+			
Picea sp.	+	3E,H		
Tsuga sp.	+			
Taxodiaceae				
Metasequoia type	+			
Sparganiceae				
Sparganium sp.		3E	+	
Potamogetonaceae				
Potamogeton sp.	+	3E	072	6A
Alismaceae				
Sagittaria sp.	?			
Cyperaceae				
Carex aquatilis Wahlenb.			+	
Carex sp.	+	3H	072	6A
Scipus sp.	+			
Juncaceae				
Luzula sp.			+	
Salicaceae				
Salix sp.			+	
S. niphoclada Rydb.			+	
S. alaxensis (And.) Cor.			+	
S. ovalifolia Trautv.			cf	
Betulaceae				
Alnus crispa type	+			
A. crispa (Ait.)			+	
Alnus incana/rugosa type	+			
Betula sp.			072	
Betula (arboreal)				
Caryophyllaceae				
Stellaria sp.			+	
Arenaria humifusa Wahlenb.			?	
Ranunculaleae				
Ranunculus sp.			072	
R. trichophyllus type		3E	072	6A
R. lapponicus L.			+	
R. Macounii-pensylvanicus typ.			072	
Capparidaceae				
Polanisia sp.	+	3H		
Crassulaceae				
Sedum sp.	+			
Rosaceae				
Dryas integrifolia Vahl.			+	
Potentilla sp.		3H	+	6A
Rubus sp.	+			
Callitrichaceae				
Callitriche sp.	+			
Hypericaceae				
Hypericum sp.	+	3H		
Lythraceae				
Decodon sp.	+	3E		
Araliaceae				
Aralia sp.	+	?3E		
Haloragaceae				
Hippuris sp.		3E		
Hippuris vulgaris L.			072	
Pyrolaceae				
Pyrola grandiflora Rad.			+	
Ericaceae				
Empetrum nigrum L.			072	
Ledum decumbens (Ait.) Lodd			+	
Andromeda sp.		3E		
Arctostaphylos alpina/ruba type			072	
Vaccinium uliginosum L. var. *uliginosum*		+		
*V.u.*ssp. *microphyllum* Lange.			+	
*V.u.*var. *alpinum* Big.			+	
V.vitis-idea var. *minus* Lodd.			+	
Gentinaceae				
Menyanthes trifoliata L.			+	
Labiatae				
Teucrium sp.	+			
Solanaceae				
Genus?		?3H		
Caprifoliaceae				
Sambucus		3E,H		
ARTHROPODS:				
COLEOPTERA				
Carabidae				
Genus?				
**Carabus truncaticollis* Eschz.[5]			+[1]	+
**Notiophilus* sp.			+	
Elaphrus sp.			+	
Elaphrus lapponicus Gyll.			+	
Diacheila polita Fald.			072	
**Dyschirius* sp.		+		
**Bembidion umiatense* Lth.			072	
Bembidion sp.			+	
Pterostichus sp.			+	
**P. nearcticus* Lth.			+	
P. (Cryobius) ventricosus grp.			072	
Amara alpina Payk.			+	
Amara sp.			+	
**Trichocellus mannerheimi* Sahlb.			+	
Dytiscidae				
Hydroporus sp.			+	
Agabus sp.			+	
Staphylinidae				
Genus ?			+	

Taxa	Beaufort lower (Tb_1)[3]	Beaufort upper (Tb_2)	Worth WP[2]	Worth DHB[2]
Olophrum sp.			072	
Micralymma type			+	
**Tachinus brevipennis* type			072	
Byrrhidae				
Genus?			+	
Chrysomelidae				
Chrysolina sp.			072	
Curculionidae				
Genus?	+		6A	
Apion sp.			+	
**Lepidophorus lineaticollis* Kirby			+	
**Vitavitus thulius* Kiss.			+	
**Notaris* sp.			+	
**Cleonus* sp.			+	
TRICHOPTERA				
Family?				
DIPTERA				
Family?			072	6A
Chironomadae				
Genus?				6A
Xylophagidae				
**Xylophagus* sp.		3E		
HYMENOPTERA				
Ichneumonidea			072	
CRUSTACEA				
Cladocera				
Daphina sp.			072	
Notostraca				
Lepiduris sp.			072	6A
ARACHNIDA				
Acari-Mesostigmata				
Trachytes type			+	
Acari-Orbatei				
Ceratozetidae			+	
Damaeidae				
Epidamaeus sp			+	
Family?			+	

Notes:
1. + = present; ++ = abundant; r = rare; numbers in some colums refer to specific samples shown on Fig. 2b.
2. WP = Worth Point; DHB = Duck Hawk Bluffs.
3. Lower Beaufort taxa listed represent preliminary identifications of samples taken at DHB in 1985. A more complete, list appears in MATTHEWS (in press).
4. Some of plants in this column were identified by M. Kuc. Also, see KUC (1974) for list of mosses and lichens from Worth Point.
5. Arthropod taxa marked with * probably do not occur on Banks Island at present.

idue from the Worth Point Fm. The most abundant conifer fossil in the lower Beaufort samples is *Abies*. *Larix* needles are rare and poorly preserved. Two types of alder "seeds" are present, probably accounting for the two types of *Alnus* pollen shown in Figure 6. All of the *Betula* "seeds" are of the arboreal type.

Coal fragments and amber are present in samples VH-81-3E and 3H, representing an upper member of the Beaufort Fm. Like the lower member they contain *Decodon* (waterwillow) and *Polanisia* (clammy weed), plus *Sambucus* (elderberry), all taxa that presently have their northern limit south of the southern border of the Northwest Territories (Fig. 5). Unlike the lower member, the samples from the upper member display a less diverse assemblage of conifers, *e.g.*, the only conifer fossils in samples VH-81-3H and 3E are rare needles and needle fragments of *Picea*.

WORTH POINT FORMATION

Sample VH-81-6A from the eolian unit at Duck Hawk Bluffs yielded few macrofossils, but those that were recovered indicate a pond environment. This helps to explain the occurrence of relatively high percentages of *Pediastrum* shown in the pollen diagram (Fig. 6).

The plant macrofossils from the Worth Point Fm. at WP are unusually well preserved considering that they are likely older than 730 ka. For example, KUC (1974) recorded several species of foliose lichens and many of the higher plant fossils retain leaves, buds and flower parts. The few insect fossils from samples studied by Kuc are also exceptionally well preserved.

One of KUC's (1974) samples, an autochthonous moss peat, was re-examined for this paper. It contains leaves and seeds of *Empetrum nigrum* and *Salix* and seeds of *Ranunculus lapponicus*. *Larix* is represented by both needles and seeds, but neither are abundant.

MORGAN BLUFFS FORMATION

Macrofossils from the Morgan Bluffs Fm. at DHB and other localities on the island as well as from the few examined samples of the Cape Collinson Fm. are listed in Table III.

The most remarkable feature of Morgan Bluffs Fm. samples at DHB is that several of them contain well preserved needles (and in some cases seeds) of *Larix*. Many of the same samples also contain *Larix* pollen (Fig. 6). Several other plants listed in Table III and some of the insect taxa are not found as far north today. One of the prominent taxa is shrub birch, which, as suggested earlier, barely grows now on southern Banks Island. *Alnus* may also have been present. Among probable extralimital insects are *Dyschirius*, *Lepidophorus lineaticollis*, *Vitavitus* and *Hypera*.

TABLE III

Plant and arthropod macrofossils from Pleistocene interglacial and interstadial sediments, Banks and Victoria islands

			Morgan Bluffs Fm.				Cape Coll. Fm.		Prince of Wales Fm.	
Taxa	[2]EJB	ENR	DHB	IR	TR	ENR	DHB	DD	DR	GvB
			«PLANTS»							
Characeae										
Chara/Nitella sp.			10E[1] 9D							+
Bryophyta			10B,D,11A,C. 11D,12B,C					+		+
Equisetaceae										
Equisetum sp.	+	+			+	+				+
Selaginellaceae										
Selaginella sp.										+
Pinaceae										
Larix sp.			9D,10D,E 11A,C,D							
Sparganiaceae										
Sparganium sp.	+	+				+				
Potamogetonaceae										
Potamogeton filliformis Pers.					+			+		++
Potamogeton sp.	+	+	10D,11C,12C		+	+				
Graminaeae										
Genus ?								+		
Cyperaceae										
Carex aquatilis Wahlenb.	+	+	12A		+	+				+
Carex sp.	+	+	10D,E 11A,B,C,D		+	+	5B	+	+	+
Carex maritima Gunn.								+		
Kobresia sp.										?
Scirpus sp.	+	+				+				
Juncaceae										
Luzula sp.	+	+				+				
Salicaceae										
Salix sp.	+	+	12A,B?		+	+		+		++
Betulaceae										
Alnus sp.			11A?							
Betula glandulosa type			10E 11C,D,12A		+	+				
Betula sp.	+	+	11A			+				
Polygonaceae										
Oxyria digyna (L.)Hill										+
Caryophyllaceae										
Cerastium sp.								+		
Melandrium apetalum (L.)Fenzl.										+
Melandrium sp.					?					
Stellaria sp.	?	?				?				
Ranunculaceae										
Ranunculus sp.	+	+	12B,C			+		+		
R. trichophyllus type			*12C,10D*					+		
R. lapponicus L.	+	+				+	5B			
Cruciferae										
Draba type								+		
Genus?					+					
Rosaceae										
Dryas sp.								+		
Dryas integrifolia Vahl		+	12A		++	+		+		+
Sibbaldia procumbens L.			11Ccf							
Potentilla palustris (L.) Scop.			10D,12A					+		

Taxa	[2]EJB	ENR	Morgan Bluffs Fm. DHB	IR	TR	Cape Coll. Fm. ENR	DHB	DD	Prince of Wales Fm. DR	GvB
Potentilla sp.			11D,12C		+			+		
Rubus chamaemorus L.										
Leguminosae										
Genus ?								+		
Haloragaceae										
Myriophyllum sp.			11D							
Hippuris sp.		+			+	+	5B			
Ericaceae										
Empetrum nigrum L.			10D,E 11D,12A, 12C							
Cassiope sp.			12B							
Arctostaphylos alpina/ruba type			12A							+
Gentianaceae										
Menyanthes trifoliata L.	+	+	11C		+	+				
Compositae										
Taraxicum sp.								+		
			«ARTHROPODS»							
BRYOZOA										
Cristatella mucedo L.			10D,E,11C,D[1]							
Genus?								+		
ARTHROPODA										
INSECTA										
HEMIPTERA										
Miridae								+		
HOMOPTERA										
Cicadellidae										
Genus?									+	
COLEOPTERA										
Carabidae										
Genus?			+							
**Carabus truncaticollis* Eschz.[3]	+									
**Notiophilus* sp	+H	+		+		+				
**Elaphrus* sp.	+	+		+		+			+	
**Elaphrus lapponicus* Gyll.	+	+		+		+				
**Diacheila polita* Fald.							5B		+	
**Dyschirius* sp.	+H	+	11C	+		+				+
**Dyschirius frigidus* type									+	
Bembidion (Platophodes) sp.			10E							
Bembidion umiatense Lth.	+	+	+		+	+				
Bembidion sp.	H	+			+	+		+		
Pterostichus sp.	+H	+	11C,12C	+		+				
**P. nearcticus* Lth.	+	+		+		+				
P. (Cryobius) cf. *kotzebuei* Ball					+					
P. (Cryobius) ventricosus Eschz.	H		+		+					
**P. (Cryobius) brevicornis* Kby.	H		10E,12C		+				+	
P. (Cryobius) sp.	+	+	10D,E 11D,12A,C	+		+				+
**Pterostichus haematopus* Dej.										+
Amara alpina Payk.	+H	+		+	+	+				+
Amara sp.	+	+		+		+		+		
Harpalus sp.			11D?							
**Trichocellus mannerheimi* Sahlb	+H	+		+		+				
Dytiscidae										
Genus?	H				+			+		+
Hudroporus sp.	+	+		+		+				
Agabus sp.	?	?		?		?				

			Morgan Bluffs Fm.				Cape Coll. Fm.		Prince of Wales Fm.	
Taxa	[2]EJB	ENR	DHB	IR	TR	ENR	DHB	DD	DR	GvB
Ilybius sp.	?	?		?		?				
Colymbetes sp.			10D,12A,C							
Gyrinidae										
**Gyrinus* sp.										+
Hydrophilidae										
Hydrobius sp.										+
Hudraenidae										
Genus?	H									
Staphylinidae										
Genus ?	+	+	9D	+		+				
Bledius sp.			10E							
Omalinae			+							
Olophrum sp.	+	+		+		+				
Olophrum latum Makl.	+	+		+		+				
Macralymma brevilinque type	+	+		+	+	+				+
Stenus sp.	+H	+		+		+			+	
**Euaesthetus* sp.		+							++	
Tachinus sp.	H		+							
Tachinus apterus Maklin					+					
Tachinus brevipennis Sahlb.	+H	+		+		+				
**Tachinus instabilis* Maklin	H									
Aleocharinae	H		9D,10E,11D							
Genus?		+	+						+	
Silphidae										
**Silpha* sp.										+
Leiodidae										
Agathidium sp.										+
Genus?	H									
Byrrhidae										
Genus?	+	+		+		+				
Simplocaria sp.					+					
Simplocaria remota Brown									+	
**Morychus* sp.								+		
**Byrrhus* sp.									+	
Coccinellidae										
Scymnini								+		
Ceratomegilla sp.								+		
Curculionidae										
Genus?			10B,11D							
Apion sp.	+H	+		+		+				+
**Lepidophorus lineaticollis* Kirby	+	+	11D	+		+				
**Vitavitus* sp.			11D							
**Vitavitus thulius* Kiss.	+	+	10D,E	+	+	+				+
Hypera sp.			10D					+		
Hypera diversipunctata Schrank			+							
**Sitona* sp.										?
**Lepyrus* sp.								+		
**Notaris* sp.	+	+		+	+	+				
Rhynchaenus sp.			12C							
**Cleonus* sp.	+	+		+		+				
Ceutorhunchus sp.					+					
TRICHOPTERA										
Family?			9D,10D, 11D,12B					+		+
LEPIDOPTERA										
Genus?			10B		+					
DIPTERA			9D							
Family?			10E					+		+

Taxa	Morgan Bluffs Fm. [2]EJB	ENR	DHB	IR	TR	Cape Coll. Fm. ENR	DHB	DD	Prince of Wales Fm. DR	GvB
Tipulidae										
Tipila sp.								+		
Chironomidae										
Genus?	+	+	11D	+		+		+		
Calliphoridae								+		
HYMENOPTERA										
Family?			11D							
Symphyta										
Tenthredinidae					+			+		
Ichneumonoidea					+					
Genus?		+								
Diapriidae					+					
Cynipoidea										
Genus?								+		
CRUSTACEA										
Cladocera										
Daphina sp.			12A,B,C		+			+		+
Notostraca										
Lepiduris sp.			10E, 12A,B,C		+					
Ostracoda										
Genus								+		
ARACHNIDA										
Acari										
Oribatei										
Genus?			9D,11C 11D,12B						+	
Araneae										
Lycosidae?			11D						+	

Notes:

1. + = present; + + = abundant; r = rare; number in some columns refer to specific samples shown on Fig. 2b. Taxa marked as H represent those identified by R. Miller in unpublished report to C.R. Harington on samples from the Morgan Bluffs Formation East of Jesse Bay.
2. WP = Worth Point; DHB = Duck Hawk Bluffs; EJB = East of Jesse Bay (Morgan Bluffs Fm. stratotype); ENR = East of Nelson River (Cape Collinson Fm. stratotype); IR = "Ivitaruk" River site; TR = Thomsen River site; DR = Dissection River site; DD = Deans Dundas Bay, Victoria Island; GvB = Graveyard Bay (Victoria Island)
3. Arthropod taxa marked with * probably do not occur on Banks Island at present.

The TR site, which is thought to be correlative with the Morgan Bluffs Fm., also yielded fossils of shrub birch, *Potamogeton, Menyanthes*, and *Hippuris*. Such fossils constitute even stronger evidence of warmer climate on Banks Island than if they occurred at DHB because the TR site is located much further north than DHB (Fig. 1). The absence of conifer fossils in the TR assemblage suggests that the site was treeless, a conclusion supported by fossils of such typical tundra beetles as *Carabus truncaticollis, Amara alpina* and *Bembidion umiatense*. Curiously, the TR assemblage also contains fossils of the rare weevil *Vitavitus thulius* but none of *Lepidophorus lineaticollis*. The latter is nearly always present in mainland samples, while *Vitavitus* is less common. Living specimens of *Vitavitus thulius* have been collected on the dry warm south-facing slopes and *Dryas* fell-field sites in the northern Yukon. Leaves of *Dryas intergrifolia* dominate the TR plant macrofossil assemblage.

Very few plant macrofossils occurred in the IR paleosol sample (Fig. 1, Table III), but the insect fossils clearly suggest a climate warmer than at present.

CAPE COLLINSON FORMATION

The fossil record from the Cape Collinson Fm. in the DHB region is limited to a single sample from section J (Fig. 2b), which contains (Table III) *Ranunculus lapponicus*, and the ground-beetle *Diacheila polita*, neither of which live on Banks Island today. Samples from the Cape Collinson Fm. type locality (ENR) contain *Betula glandulosa, Sparganium, Potamogeton, Ranunculus lapponicus* and *Menyanthes trifoliata*. None of these species grow at the site today.

The arthropod fauna from the Cape Collinson type locality is much richer and more informative than the assemblages at DHB. It contains *Notiophilus, Elaphrus lapponicus, Dyschirius, Pterostichus nearcticus, Lepidophorus lineaticollis, Cleonus, Notaris* and *Vitavitus thulius*, most of which are unlikely to occur on Banks Island today.

Although the organic sediments at Deans Dundas Bay on Victoria Island contain amber, megaspores, and coal that normally indicate the possibility of redeposited Tertiary macrofossils, none of fossils listed in the table is obviously of that age. Nevertheless, some of them (*e.g.*, the plant *Potamogeton filiformis* and the insect genera *Hypera* and *Lepyrus*) do appear to represent slightly warmer climate, because they do not occur as far north as the site today.

AMUNDSEN GLACIATION AND HOLOCENE SITES

The finite radiocarbon date (49.1 ka BP:GSC-2375-2; VINCENT, 1983), from the DR site (Fig. 1) suggests that it is of interstadial age, but the date requires confirmation before such a conclusion is justified. The site is located well north of DHB yet the insect fauna contains beetles such as *Elaphrus, Dyschirius* and *Euaesthetus* that undoubtedly do not live in the area today and may not even inhabit southern Banks Island.

At the Graveyard Bay site on Victoria Island (VH-82-131) (Fig. 1) organics occur in fluvial and lacustrine sediments wedged between tills of the Amundsen Glaciation (Fig. 4). *Potamogeton* is present, north of its presently mapped limit (PORSILD and CODY, 1980), but unlike the DR assemblage, most of the other taxa in the Graveyard Bay assemblage probably live near the site today.

To date only two Banks Island Holocene macrofossil assemblages have been studied. Both have a fossil content in accord with the present fauna and flora of the island. One from 22 km SE of the mouth of Bernard River (BR in Fig. 1) is dated at 8.9 ka BP (GSC-2776; VINCENT, 1983) and has yielded fossils of the beetles *Pterostichus (Cryobius)* sp., *Simplocaria remota* and the ladybird beetle *Ceratomegilla*. The only plant fossils present are seeds of *Carex*, probably *C. stans* (= *C. aquatilis*) and leaves of *Dryas integrifolia*. Another assemblage of plants and insects (SH in Fig. 1), dated at 6490 ± 60 ka BP (GSC-3216), from 4 km southeast of Sachs Harbour (Fig. 1), contained a few *Carex* seeds, fragments of the beetle *Pterostichus (Cryobius)* sp., the water beetle (*Hydroporus*) and the weevil *Rhynchaenus arcticus*, all of which probably occur on southern Banks Island today.

DISCUSSION

NEW DATA ON THE BEAUFORT FORMATION

Samples VH-81-3E, 3H, and 3G are sedimentalogically very different from the bulk of Beaufort Fm. beds exposed at DHB, a fact which prompted VINCENT *et al.* (1983) to group them with the Worth Point Fm. But their fossil content shows that they are more likely allied with the Beaufort Fm. Like the typical Beaufort Fm. sediments they contain *Polanisia, Aralia?, Hypericum, Decodon* and other taxa that suggest a climate significantly warmer than is indicated by fossils from the Worth Point Fm. type locality (Fig. 5). The pollen spectra from VH-81-3E and 3H also resemble those from the Beaufort Fm., chiefly by their content of hardwood pollen, traces of *Abies*, and in one of them (VH-81-3H), significant amounts of *Tsuga*. Accordingly what was formerly defined as a lower member of the Worth Point Fm. at DHB is shown here (Figs. 2,3,4, and 6) as part of the Beaufort Formation. It is designated here as an upper member of the Beaufort Fm. (= ? unit "Y" of HILLS, 1969) because despite the similarities mentioned above, the assemblages from samples VH-81-3H and 3E also differ from those lower in the section. The most obvious distinctions are that 3E and 3H are dominated by spruce rather than fir and have a lower diversity of coniferous macrofossils. The main Beaufort Fm. sequence at DHB thus becomes a lower member of the Beaufort Formation (Figs. 2,3,4 and 6).

The Kap København Fm. in Peary Land, northern Greenland, has yielded fossils representing a flora with a mixture of conifer taxa and tundra plants (FUNDER *et al.*, 1985). Several lines of evidence (paleontological, amino-acid racemization and paleomagnetic) show that it is probably latest Pliocene in age. FUNDER *et al.* (1985) have noted the similarities of the Kap København flora to that of the Beaufort Fm. on Meighen Island, but amino-acid studies of marine shells from the two sites (FUNDER *et al.*, 1985; J. Brigham-Grette, pers. comm. 1984) suggest to us that the Meighen Island assemblages are older. FUNDER *et al.* (1985) also note that Kap København Fm. represents the same type of conditions implied by the Worth Point Fm.; however, it is now apparent that the Worth Point Fm. has a much less diverse coniferous flora than the Kap København Fm. Since WP is located much further south than Kap København, its flora should be noticeably richer in tree species if it is correlative with Kap København. Because it is not we believe that the Worth Point Fm. is younger than the Kap København Fm. Several lines of evidence, including fossil insects, show that the Worth Point Fm. is also younger than both the Meighen Island assemblages (MATTHEWS, 1976) and the 5.7 Ma Lava Camp assemblage (HOPKINS *et al.*, 1971) in Alaska. We believe that the Kap København Fm. is intermediate in age between the Upper Beaufort member at DHB and the Worth Point Fm. and possibly about the same age as the Pliocene Ocean Point flora (NELSON and CARTER, 1985) and related Pliocene floras and faunas in northern Alaska (CARTER, 1983; CARTER and GALLOWAY, 1985).

THE BANKS ISLAND INTERGLACIAL RECORD

The fossil data presented above support lithostratigraphic evidence that both the Cape Collinson Fm. and Morgan Bluffs Fm. represent climate warmer than present, hence interglacial conditions. The DR assemblage also appears to be of interglacial age on the basis of its fauna, even though it is associated with a finite radiocarbon date. Until this date is replicated, we believe it should be considered only as a minimum estimate.

The Morgan Bluffs Fm. may correlate (CLARK *et al.*, 1984) with unit K of the Central Arctic Ocean Basin (CLARK *et al.*, 1980), a unit considered to have been deposited during a time of reduced glacial ice activity. Validation of the paleomagnetic data would also mean that the Morgan Bluffs Fm. might be equivalent to one of the warm episodes between isotope stages 17 and 21 of the deep-sea record. If so, approximately 600 ka years separate the Cape Collinson and Morgan Bluffs interglaciations. At least three interglaciations as warm or warmer than the "warm" event at the Brunhes/Matuyama boundary are recorded for this interval in the marine isotopic record (SHACKLETON and OPDYKE, 1976). Where is the record of these events on Banks Island? One possible explanation is that the Morgan Bluffs Fm. represents a complex of several rather than just one interglaciation. DHB is not the best site for testing this contingency since the Morgan Bluffs Fm. there is not very thick. It is much thicker and sedimentologically more complex at the type locality east of Jesse Bay (EJB). A detailed paleontologic study of the organic sequence at that site should be a high priority for future research especially since the EJB locality has yielded small mammal fossils, which could well be the key to dating the sequence (R. F. Miller, pers. comm., 1985).

THE PROBLEM OF REBEDDED FOSSILS

The presence of marine diatoms of Miocene age and older in sediments of the Morgan Bluffs Fm. (VINCENT *et al.*, 1983) is a warning that some of the DHB samples may be similarly contaminated by "old" palynomorphs. The Beaufort Fm. is the most obvious source and, as Figure 6 shows, some of the hardwood and conifer types in its samples occur as well in the Morgan Bluffs Fm. samples at DHB. Similar hardwood types show up as trace amounts in a Holocene sample from a region where the Beaufort Fm. outcrops (Big River site, Fig. 1; Table IV), while they are absent in another Holocene pollen sample from Able Creek (Fig. 1, Table IV) in a region where the Beaufort Fm. is not present. Neither are the hardwood pollen types evident in the pollen samples from the ENR and EJB sites, both of which are also outside the limit of the Beaufort Fm. Such facts constitute strong circumstantial evidence that the Morgan Bluffs Fm. samples at DHB are contaminated by reworked Beaufort Fm. pollen. Although the white pine (Haploxylon) type pollen and perhaps some of the tree-birch pollen (*e.g.*, that > 20 microns) is also of Beaufort origin, it is difficult to assess the degree to which the major pollen categories (spruce, pine, birch and alder) are also contaminated by Beaufort Fm. palynomorphs. We suspect that allochthonous, wind-transported pollen may be more responsible for the high percentages of spruce, birch and alder than is the Beaufort Fm., but an unequivocal evaluation is not possible at this time, and will continue to be elusive until samples from correlative units at other sites on Banks Island are studied.

The Beaufort Fm. may not be the only source of redeposited pollen in DHB samples. For example, a number of Morgan Bluffs Fm. samples at DHB contain larch pollen, and the sections from which these samples come are suspiciously clustered at the west end of the exposure where redeposited Worth Point Fm. wood may be seen in the overlying till of the Duck Hawk Bluffs Fm. As a rule, macrofossils other than wood are less likely to survive rebedding than pollen and neither samples from the Morgan Bluffs Fm. nor Cape Collinson Fm. at DHB contain the coal, amber, and *Abies* needles that would indicate contaminants from the Beaufort Fm. However, all the Morgan Bluffs Fm. samples at DHB that contain *Larix* needles and seeds come from the west part of the section where redeposited Worth Point wood is evident. Furthermore, the Morgan Bluffs Fm. samples are detrital organics, which often contain redeposited, older fossils. Thus we cannot eliminate the possibility that some or all of the *Larix* needles from the Morgan Bluffs Fm. originate in the Worth Point Fm. For purposes of the discussion that follows it is assumed that this is not the case.

TABLE IV

Comparison of Holocene pollen assemblages from sites inside and outside limits of Beaufort Fm. outcrop

Taxa	Big River[1] (inside)	Able Creek (outside)
TREES		
**Picea*[2]	7.0%	6.1
**Pinus*	10.3	7.3
**Abies*	0.3	1.8
**Tsuga*	0.3	—
**Betula*	13.0	—
**Alnus*	3.7	3.6
**Carya*	+[3]	—
**Carpinus/Ostrya*	+	—
**Castanea*	+	—
**Juglans*	+	—
SHRUBS		
Salix	+	10.4
**Corylus*	+	—
**Myrica*	+	—
**Ilex*	+	—
Ericaceae	2.2	+
HERBS		
Dryas	—	3.0
Rosaceae	1.4	—
Caryophyllaceae	+	1.2
Ranunculaceae	1.4	3.0
Saxifragaceae	+	+
*Onagraceae	+	—
Leguminosae	—	+
Gramineae	7.4	4.9
Cyperaceae	35.5	31.2
Sagittaria	+	—
Tubuliflorae	1.8	11.0
Ambrosieae	—	+
UNDET. POLLEN	6.6	6.7
POLLEN SUM:	276	163

Notes:
1. See figure 1 for location of each sample.
2. Taxa marked with * are those known to occur in the Beaufort Fm. or which have been found in Tertiary deposits elsewhere in northwestern North America.
3. + indicates trace (*e.g.*, less than 1%)

PALEOCLIMATIC IMPLICATIONS

1. Beaufort Formation

The lower member of the Beaufort Fm. at DHB was deposited at a time when rich coniferous forests containing an admixture of hardwoods existed on southern Banks Island. HILLS (1975) compares it to the existing mixed forests of the Great Lakes region of central Canada. During deposition of the upper member (samples 3E, 3H) of the Beaufort Fm. climate may have been somewhat cooler, accounting for the lower diversity of conifers. Nevertheless, the upper member contains plants (*Decodon* and *Polanisia*) that must represent a climate considerably warmer than at any site today in the Northwest Territories. In contrast with the Worth Point Fm., structures indicative of the former presence of permafrost have not been observed in the Beaufort Fm. sequence at DHB.

2. Worth Point Formation

KUC (1974) suggests that regional cooling was underway during deposition of the Worth Point Fm. peats at WP. But for part of this time the climate was at least warm enough to allow growth of conifers at coastal sites on southern Banks Island. Other plants and insects show that this was not a closed forest, although if climate trends during deposition of the Worth Point Fm. paralleled those of the present, we might expect that closed forests could have existed at inland sites. If so, mean July temperature on the southern part of the island probably approached 10°C (HARE, 1970).

Ice-wedge pseudomorphs occur in the eolian sediments of the Worth Point Fm. at DHB. This means that for a time climate must have been at least as warm as at sites within the present discontinuous permafrost zone, implying a mean annual temperature at least 6°C warmer than today in the Sachs Harbour area.

3. Morgan Bluffs Formation

Larix pollen, needles and seeds in the Morgan Bluffs Fm. samples at DHB Morgan Bluffs Interglaciation suggest that southern Banks Island lay south of treeline during the Morgan Bluffs Interglaciation. This implies mean July temperatures 4-5°C warmer than the present. If the the TR site is of Morgan Bluffs age, then for part of that interglaciation treeline probably crossed southern Banks Island. It was a *Larix* treeline rather than one dominated by spruce as at present, and this finding agrees with other evidence that *Larix* formed treeline in Alaska during at least some late Pliocene and early Quaternary warm intervals (see MATTHEWS, 1974, Cape Deceit Fm. at Deering and revised date estimates for the Cape Deceit Fm. in REPENNING, 1980 and J. V. MATTHEWS, Jr.: Unpublished Geological Survey of Canada Plant Macrofossil Report 85-13).

4. Cape Collinson Formation

Cape Collinson Fm. samples seem to be less influenced by rebedded pollen than those of the Morgan Bluffs Fm. Both plants and insects (*e.g.* shrub birch, *Ranunculus lapponicus*, *Diacheila polita*) suggest that climate was warmer than at present but not warm enough for growth of conifers on southern Banks Island. Thus the 10°C mean July isotherm probably lay south of the island.

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